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**TIME-DEPENDENT OUTGASSING AND IMPURITIES
IN THE NASA LEWIS BUMPY TORUS**

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ABSTRACT

To investigate the importance to fusion devices of desorption of gas from walls or cryosurfaces under long-time operation, preliminary mass-spectrometric investigations were carried out on the NASA Lewis Bumpy Torus with a 0.1-2A discharge in D_2 at a pressure of 4.0 to 6.6×10^{-5} torr (facility base pressure 0.5 to 1.0×10^{-7} torr).

During the initial tens of minutes of discharge operation large quantities of a component with mass number 28, believed to be nitrogen, were released; particularly large when the vessel had been open to the atmosphere for a long time. The decrease with time of the nitrogen density after its initial maximum can usually be described by a power law $[N_2] = k_1 t^k$, except when the system is very clean. Often $k \approx -0.5$ was measured, indicating a diffusion-controlled outgassing from the cryodeposits or wall material, and values near -0.3 are sometimes observed for long times. With a strongly contaminated system $k \approx -1$ was measured, indicating an increased importance of gas sorbed on or in the wall material. After the discharge is interrupted, the N_2 pressure decreases exponentially to a lower level with a time constant of 10 to 100 sec. This is much longer than the particle mean residence time in the gas phase but comparable with the estimated time for a few monolayers to build up.

During the entire discharge, the water contamination level has an essentially constant value, 15 to 40% higher than before or after the discharge.

When cold surfaces were allowed to warm up, large quantities of gas were released. The integrated amount of N_2 was typically the same as that released during a discharge, while the amount of H_2O was orders of magnitude larger. There are indications that during a discharge the pumping effect of the cryosurfaces for N_2 may be counteracted by release of gas.

INTRODUCTION

Questions concerning outgassing from walls and cryosurfaces in

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fusion devices as well as release of the wall material itself and the interaction of these particles with the hot plasma, especially their cooling effect, is a subject of increasing interest in fusion research. It may take a long time - minutes or hours - for this plasma-wall interaction to reach a steady state.

It is of interest to study the outgassing before a steady state is attained, in particular, the form of the variation in time, from which information can be obtained about the physical processes involved. The influence of the conditions - both the vacuum vessel contamination and prehistory, and the experimental parameters - are factors worthy of a study; and an important characteristic of the final plasma is its cleanliness. A knowledge of the influence of cryosurfaces (of magnets) is also desirable. Such surfaces have a double action; on one hand they may pump the impurities, on the other their deposit constitutes a large supply of gas that may be released by particles incident from the plasma.

The NASA Lewis Bumpy Torus contains a few elements one would expect in a future fusion reactor, like cryosurfaces, a plasma with hot ions at least approaching fusion temperatures, and long experimental times. Furthermore, it is possible to follow the net result of the double action that any gas discharge has - release of sorbed gas as well as pumping action. The cryosurfaces in the NASA Lewis Bumpy Torus may be critical; they are neither remote from the plasma, nor electrically passive; some shielding is furnished by the actual magnetic field. However, similar relations between the plasma and the cryosurfaces may be encountered in future fusion devices.

About 1000 mass spectra were taken using a quadrupole mass filter. Most of the measurements were intended to give the densities of impurities as functions of time during operation with some variation of the conditions. A few studies of the (almost) steady-state spectra were made, as well as analyses of the gas that was released - without any discharge - when cold surfaces were allowed to warm up.

The present report summarizes the measurements and includes a discussion of the results.

THE BUMPY TORUS

The NASA Lewis Bumpy Torus (ref. 1) is a steady-state discharge between the anode rings (normally 12 in number) around the plasma torus and the grounded stainless steel vacuum vessel together with the essentially grounded LN₂-shields surrounding the LHe-dewars for the 12 superconducting magnet coils. D₂ gas is continually bled in at a variable rate, and the gas present in the gas phase in the tank is continually pumped away with the full capacity of the pumping system, including that of the cold surfaces (ref. 1).

The time constant of the pumping is about 1 sec (even if the pumping

by the cryogenic surfaces would become inactive during discharge), so the details of the pumping can be neglected on time scales longer than a few seconds, and the partial pressure observed is a direct measure of the outgassing rate, which can be obtained by multiplication by the pumping speed, which is approximately constant for the pertinent pressures (ref. 1).

MEASUREMENTS

The head of the mass filter, a commercial quadrupole residual gas analyzer, was placed in an air lock in the bottom of the vacuum tank at a distance of about 30 inches from the vertical axis of the apparatus. The filament, that was protected by a stainless steel shield, was situated about 15 inches below the bottom. Some influence on the performance from the sheltered position was observed, and some fractionation was expected. However, the response to transient changes was good, and the measurements of the variation on the time scale used (10 to 10^4 sec) are believed to be rather reliable. It is understood that - for the sake of sensitivity - the resolution had not been driven to its extreme; yet it is believed that the mass number can be properly identified with the best settings used. It was, however, not always possible to follow in detail the rapid changes at the very beginning of a discharge.

RESULTS

Figure 1 shows a typical curve representing the common logarithm (base 10) of the nitrogen density $[N_2]$ (arbitrary units) as a function of the common logarithm of the time t (min) measured after the start of the discharge. The component measured has mass number 28, and from optical spectroscopy it is known (ref. 2) that it consists of N_2 rather than CO or Si. The curve was obtained with a medium-clean system (under vacuum but out of use for about a day). The D_2 pressure P_1 was 4.1×10^{-5} torr and the discharge voltage V was 5.0 kV; the current I was about 0.22 A. For these parameters, the plasma is characterized by a density of a few times $10^9/\text{cm}^3$; the ion and electron temperatures are 400 and 20 eV, respectively. The initial nitrogen density before the start of the discharge is given by $^{10}\log[N_2] = 2.46$, which corresponds to a partial pressure of about 10^{-7} torr - about 1/4% of the total gas content. The density reaches a maximum corresponding to about 4.5%, and then it falls below its initial value. The fall-off after the maximum is fairly well linear, with a slope $k = -0.58$. In some experiments, other k values (-0.30, -0.32, -0.37) are observed at late time. More than a month earlier, the experiment was run with essentially the same parameter values as in figure 1, however, with a more contaminated tank. Apart from the maximum of $[N_2]$, which was almost one order of magnitude higher, the curves were practically identical.

In figure 2, the result is shown for the same settings of the discharge parameters when the tank was strongly contaminated. Before this

run, it had been open to the atmosphere for several months and only a few discharges had been run in it. The initial outgassing is quite strong; for several minutes N_2 is the dominating gas in the vessel. The decrease is reasonably linear, but the fall-off is much more rapid ($k = -1.2$).

Figure 3 shows data for a clean system; no straight line can be fitted to the points. Even though the discharge current is higher for figure 3 than for figures 1 and 2, the initial outgassing is moderate. ($P_1 = 6.6 \times 10^{-5}$ torr, $V = 10$ kV, $I = 1.8$ A), and an only slowly varying outgassing rate is quickly established. The data were taken in the afternoon of a day when a lot of data had been taken in the morning.

After the discharge is interrupted, the N_2 pressure decreases exponentially to a lower level with a time constant of 10 to 100 sec.

The H_2O pressure has a rectangular variation with one constant value before the discharge, one during, and one after it. Usually, the H_2O concentration is approximately the same before and after the discharge and 15 to 40% higher during the discharge.

When the LHe-cooled surfaces were allowed to warm up to about LN_2 -temperature, only D_2 was released. Allowing also the LN_2 -surfaces to warm up (to room temperature) an outgassing of N_2 , some D_2 and probably also H_2 , later CO_2 and - finally - large quantities of H_2O were observed.

DISCUSSION

In the present investigation, no attempt was made to identify all impurities, nor to carefully determine their relative abundances, taking detailed geometrical effects, exact values of gauge factors, etc. into account; the equipment was not suitable for this. In particular, sputtered metal could not be detected. Nor have the steady-state outgassing rates been determined for a dense net of values of the experimental parameters, i.e., discharge current and voltage, pressure, magnetic field, and type of mode, since this would have required long time high power operation. The main objective was to determine the level of some dominant impurities, and to study their time dependence and variation with the system cleanliness.

An exponential variation of the outgassing rate Q , like $Q = K_1 \exp(-t/T)$ or similar expressions, is typical for one-step, first-order processes, like simple pumpdown of a given amount of gas.

On the other hand, a power-law dependence, $Q = k_1 t^k$ is typical for multi-step processes like diffusion and random walk. An important special case is $k = -0.5$ which represents the solution for early times of Fick's law of diffusion applied to a slab initially homogeneously filled with gas (ref. 3). This value of the exponent is sometimes found in vacuum gauge clean-up (ref. 4), and in the outgassing of water from glass by baking (ref. 5). The value $k = -1$ is often found in the outgassing of

metals by baking (ref. 3). Martin and Lewin (ref. 6) found the values -0.6 and -0.75 in investigations of the outgassing after discharge pulses in a stellarator.

In the present investigations, the often found values near -0.5 for a medium-clean system suggest that the outgassing is diffusion-controlled. However, it is not yet clear where the diffusion takes place. The initial maximum is believed to correspond to a quick desorption of loosely adsorbed surface layers.

Incidentally, the total amount of N_2 released during the run corresponding to figure 1 is about the same (~ 20 torr l) as that released one month later when the LN_2 surfaces were allowed to warm up. This may be a coincidence, but it is also an indication that the nitrogen observed is initially located and then diffuses out through the cryodeposit. The latter consists mainly of more tightly bound water; most of it probably introduced during leakage associated with failures of the water-cooled anode rings.

In this picture, a high degree of contamination would mean that the wall material is well filled with gas, and the $k \approx -1$ dependence found in this case would be in agreement with what is empirically found for thermal outgassing of metals (ref. 3).

In an alternative picture, similar to what has been suggested for the outgassing of water from glass (ref. 5), the diffusion takes place in the wall material. The main action of the discharge would then be to keep the walls sufficiently clean from adsorbed layers to let the gas absorbed in the wall material diffuse into the gas phase, following Fick's law. This is partly supported by the observation of the decay time for the outgassing after the discharge is stopped. In order of magnitude it agrees with the estimated time it takes for a few monolayers of gas to build up. In this picture, the $k \approx -1$ variation for a dirty system would be due to a simultaneous desorption of adsorbed and absorbed gas due to the presence of massive surface layers (with $k \approx -0.5$ the adsorbed gas disappears first, cf. Todd (ref. 5)).

The possibility is still being contemplated that the observed time dependence is due to a random walk of the particles inside the tank during which they either get adsorbed for some time on active or cold surfaces or trapped in the cryodeposits or wall material (cf. Govier and McCracken (ref. 7)). The absence of any power-law dependence with a clean system indicates that there is then only a little gas that diffuses.

The pumping, i.e., the mechanism of removal of the desorbed gas, is not yet fully known. Govier and McCracken, in investigations of gas discharge cleaning of vacuum surfaces, ascribe the clean-up observed to trapping of the particles in the wall material. In the bumpy torus, the mechanism of removal may in part be pumping by the vacuum system; its time constant appears to be one order of magnitude shorter than in the

Govier-McCracken experiment. The cryosurfaces have an at least comparable pumping capacity and may be important sinks too, unless outgassing from them dominates.

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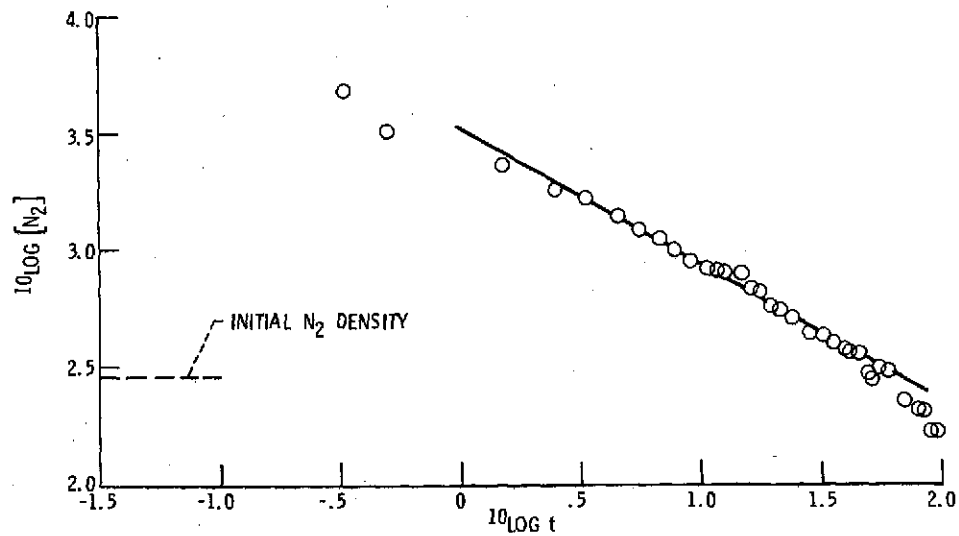


Figure 1. - Plot of the logarithm of the nitrogen density $[N_2]$ (arbitrary units) as a function of the logarithm of the time, t (in minutes), elapsed after onset of the discharge; medium-clean system; $[N_2]$ versus t follows a power law with exponent -0.58.

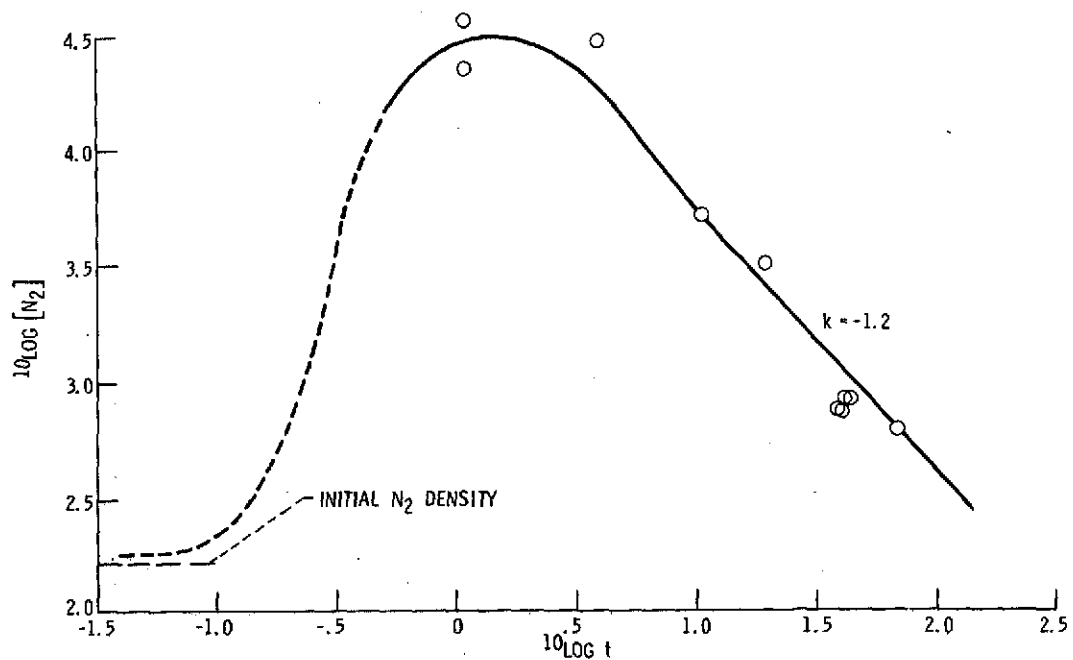


Figure 2. - $10 \log [N_2]$ versus $10 \log t$; contaminated system; $[N_2]$ versus t follows a power law with exponent -1.2.

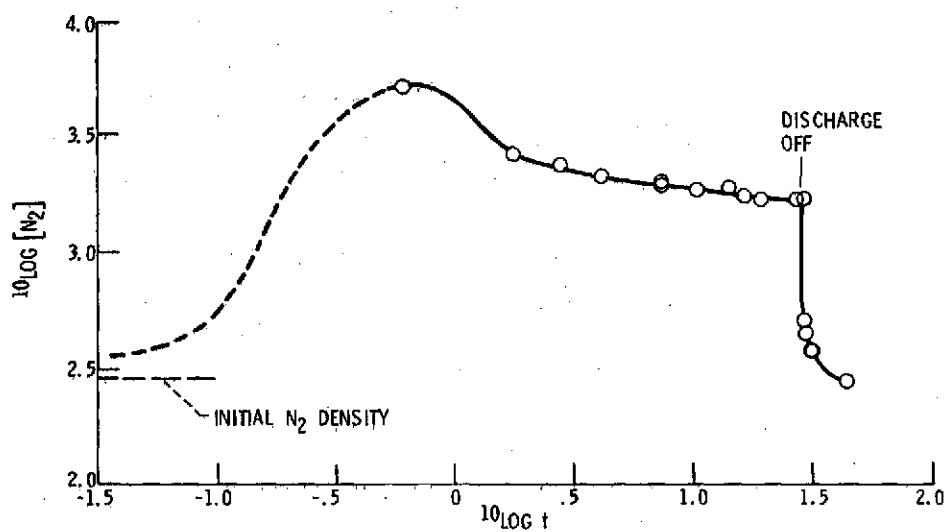


Figure 3. - $10 \log [N_2]$ versus $10 \log t$; clean system and higher current; no power-law dependence between $[N_2]$ and t .